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A REVERSE OSMOSIS PLANT FOR MAPLE SAP CONCENTRATION

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ABSTRACT

An apparatus is described which is being used for partial concentration of maple sap by reverse osmosis. The unit is of commercial size with a design capacity of 360 gallons of sap per hour at 600 p.s.i.g. The unit is equipped with necessary pressure, quality and flow controls to enable the scientist to evaluate its performance.

This is a report of work done at the

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A REVERSE OSMOSIS PLANT FOR MAPLE SAP CONCENTRATION

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The Eastern Utilization Reverse Osmosis Concentrator (EUROC), an experimental plant designed and constructed for the concentration of maple sap, uses the principles of reverse osmosis. The development of this plant serves a dual purpose--(1) to apply laboratory theory and experimentation of a pilot plant to simulated commercial operation; and (2) to test plant scale efficiency, operation, and concentration limits. The experimental plant establishes criteria for optimum operating pressure versus product flow and operating costs.

EUROC has a design feed rate of 360 gallons per hour with a maximum feed rate of 480 gallons per hour at 600 pounds per square inch gage (p.s.i.g.). At design conditions the plant consumes 6.4 kilowatts (kw.) of electric power. The feed capacity is about one-half that of the average-sized central maple sap processing plant's thermal evaporator. This publication discusses the construction features of the EUROC.

CONSTRUCTION CRITERIA

The project required that the EUROC be transported to various field locations where adequate sap supplies were available. Therefore, the plant was designed to be as compact as possible with the structural strength to be moved without destroying the alinement of critical parts. The construction and assembly of the various components were designed to place the center of gravity of the unit as close to the geometric center as possible (fig. 1).

The EUROC frame is of all-welded steel construction. The base consists of two structural channel sections running the full length of the unit, and with the formed ends functioning as skids. Lateral and torsional strength of the base is achieved by an "X" frame construction using flat stock, with end spreaders and pump base supports of angle sections. An integral pump and motor base of welded 3/16 inch steel plate is mounted on the frame base by six 5/8 inch diameter machine bolts. The one-piece rigid pump base assures true alinement of the pump, drive, and motor at all times. A structure consisting of horizontal and vertical channel sections provides support for the pressure vessels and automatic controls.

Eight pressure vessels contain the reverse osmosis modules. They are mounted in two tiers of four vessels each above the pump and are

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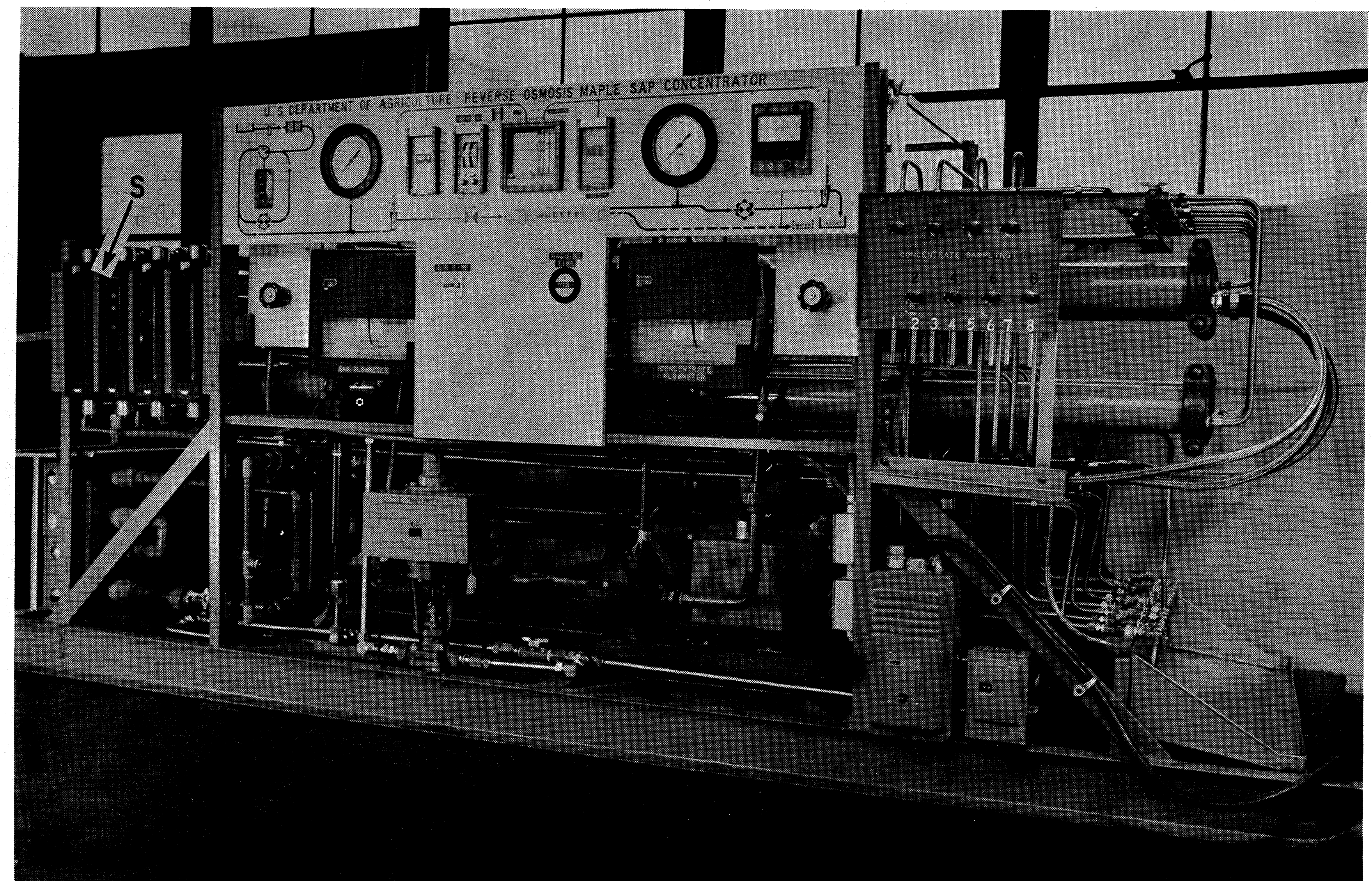

Figure 1.--The EUROC, a reverse osmosis maple sap concentrator: S, permeate flowmeters.

supported at the quarter points by standard 4-inch pipe rollers bolted to the channel sections.

The high-pressure feed and concentrate-discharge piping is of 0.20 wall, type 304 stainless steel tubing, connected where necessary with stainless steel double ferrule compression fittings to withstand operating pressures up to 1,000 p.s.i.g., and to provide experimental flexibility and sanitary operation. The low-pressure feed and permeate discharge piping is schedule 80 polyvinyl chloride pressure pipe, which permits the use of threaded fittings where necessary, and has the strength to withstand the suction pressure of the pump.

All controls, indicators, and sampling taps are located at the front and left end of the unit for ease of control and to permit convenient monitoring of the performance of the unit (figs. 2, 3, 4).

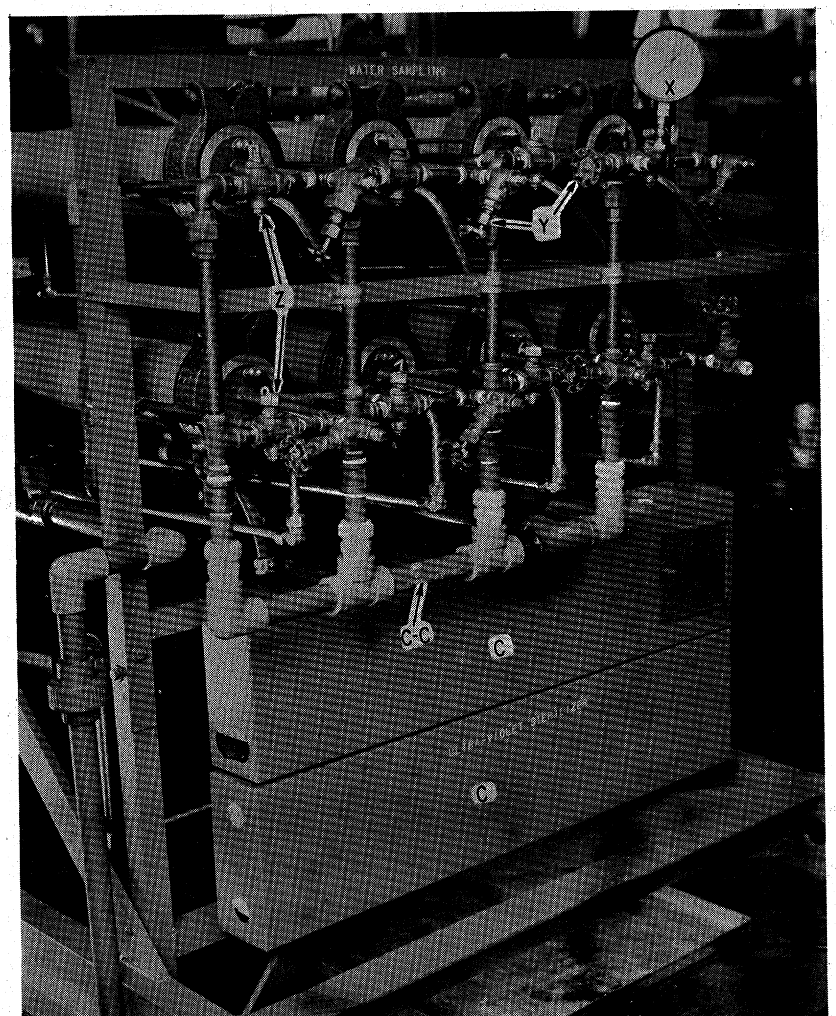

Figure 2.--The EUROC, right end showing the permeate collection manifold and ultraviolet sterilization units: C, ultraviolet sterilization unit; X, permeate pressure gage; Y, permeate sampling valves; Z, flow diverter valves; and CC, ultraviolet sterilizer units.

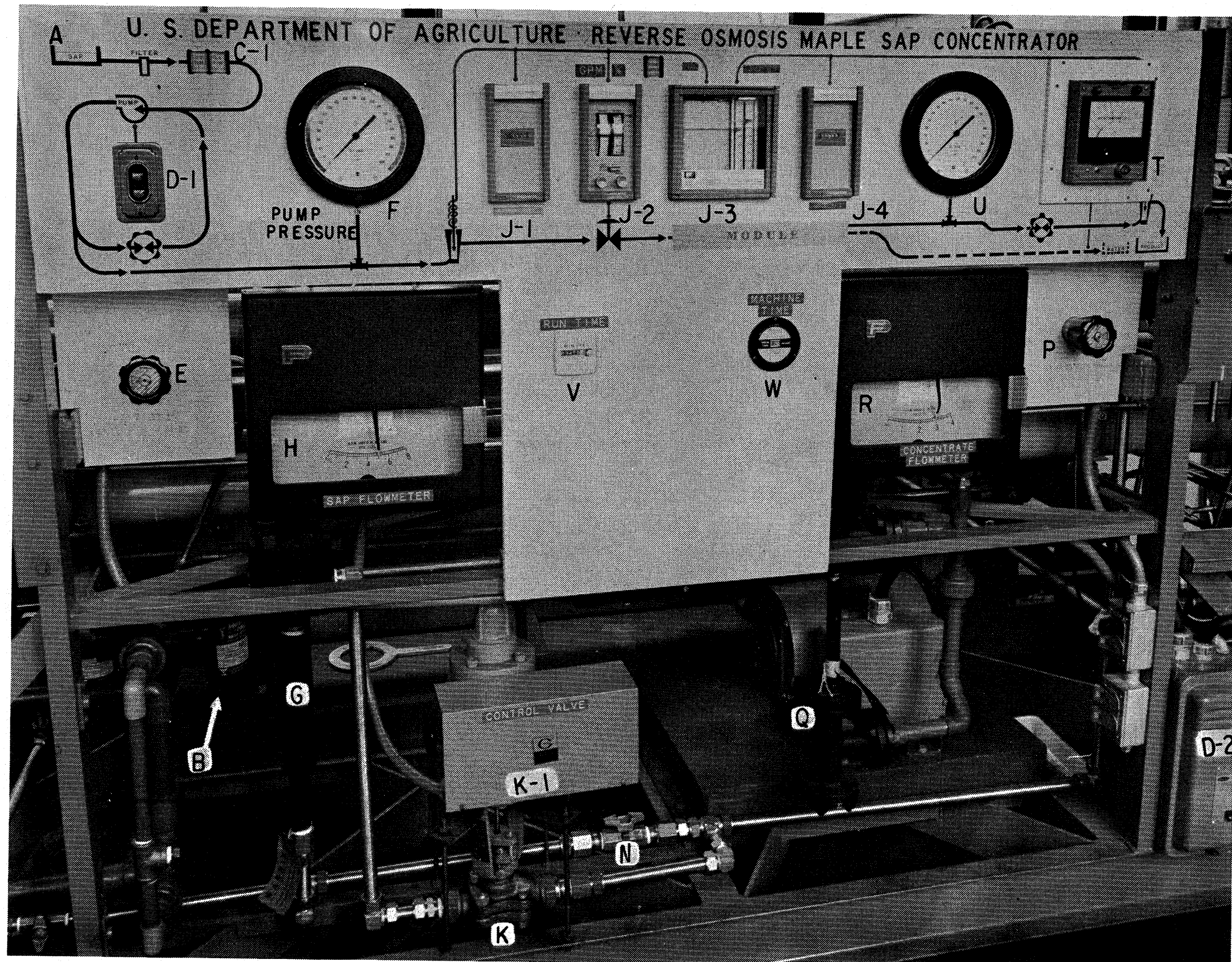

Figure 3.--The EUROC, front control panel: A, representation of producer's sap supply; B, cartridge filter; C-1, ultraviolet lamp controls. D-1, pump control; D-2, pump magnetic starter; E, pump bypass valve; F, pump pressure gage; G, sap flowrator; H, sap flow indicator; J-1, sap totalizing unit; J-2, sap flow controller; J-3, flow recorder; J-4, concentrate totalizing unit; K, flow control valve; K-1, control valve actuator; N, control valve bypass; P, pressure vessel control valve; Q, concentrate flowrator; R, concentrate flow indicator; T, conductivity meter; U, pressure vessel pressure gage; V, run elapsed time meter, minutes; and W, machine time meter, hours.

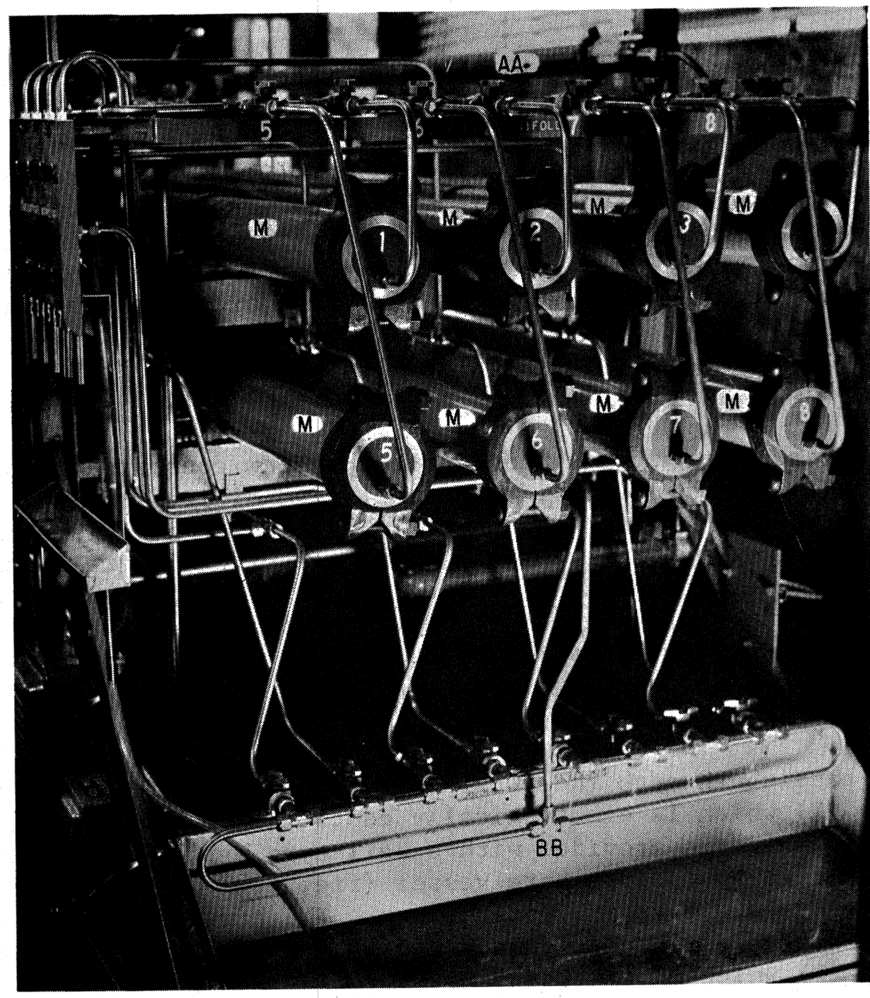

Figure 4.--EUROC, left end showing the distribution manifolds: M, pressure vessels; AA, sap supply manifold; and BB, concentrate collection manifold.

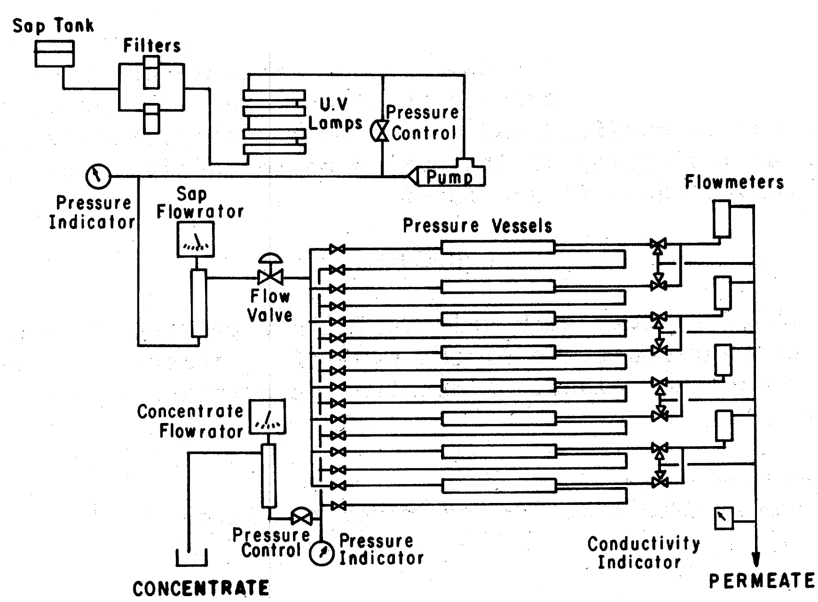

Figure 5.--EUROC flow diagram.

Figure 5 shows the relationship of all the components of the EUROC plant. Sap is supplied from the producer's storage tank (A)[2] to the unit through 1 1/4-inch rigid plastic pipe entering the EUROC system at the rear. The sap first passes through a cartridge filter (B), flows through the ultraviolet (UV) germicidal units (fig. 2,C), and is then drawn into the pump (D). The pump is provided with an adjustable bypass valve (E) for protection and to control pump output pressure. Pressure gage (F) indicates the pump output pressure. The sap passes at high pressure through flowrator (G). The flowrator is magnetically coupled to gage (H) and the flow indication is in turn transmitted to the electronic indicating and control system (J) by the gage mechanism.

The electronic indicating and control system consists of four units. A sap totalizing unit (J-1) provides a cumulative digital readout of the gallons of sap flowing through the unit. A sap flow controller (J-2) automatically controls valve "K" to maintain the preselected rate of sap flow. The flows of sap and concentrate are recorded in gallons per minute (g.p.m.) by the two-pen strip chart recorder (J-3). The concentrate totalizing unit (J-4), which is identical in operation to the sap totalizing unit, provides a cumulative digital readout of the gallons of concentrate flowing from the unit.

After passing through the flowrator, the sap flows through the flow control valve (K) which is electronically controlled and electrically operated. This valve is provided with a ball-type bypass valve (N). The sap then flows through the pressure vessel (fig. 4,M) where the reverse osmosis modules separate water from the sap. The high-pressure concentrate is collected in a valved manifold and then passes through a back-pressure control valve (P) which controls the pressure in the pressure vessels. The concentrate passes at a lower pressure through the concentrate flowrator (Q), which is similar to flowrator (G), and is coupled to flow gage (R). The electronic flow signal is transmitted to the second pen of the recorder (J-3) and totalizer (J-4). The concentrated sap then leaves the unit and is ready for the final stage of concentration by thermal evaporation.

The permeate (water that has passed through the semipermeable membrane) leaves the pressure vessels at 1 to 3 pounds pressure and flows through rotometers (fig. 1,S) which indicate the flow rate. The permeate is then collected in a common manifold and passed over a conductivity sensing element which provides an indication of its purity on conductivity meter (T). The permeate then leaves the unit and is discarded.

EQUIPMENT

In the EUROC system, each unit fulfills a particular requirement and was chosen to be representative of the type of equipment that could be employed in a production plant. A detailed description of the equipment is given below.

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[2] Unless otherwise indicated, letters refer to figure 3.

The primary filter is a cartridge-type with a 50-micron mesh cartridge installed. Two filters are mounted in parallel with appropriate valving so that one of the filters can be changed when necessary without interruption of the operation of the plant. The filter removes particulate suspended material, which may coat the reverse osmosis membranes and shorten the life of the modules.

To reduce the bacterial contamination of the raw sap feed, an assembly of four 36-inch ultraviolet lamps is arranged so that the sap flows over the lamps in series. Sap flows in a 1/2-inch concentric layer around each lamp. This arrangement reduces the bacterial count more than 90 percent at flow rates up to 600 gallons per hour.[3] The lamps are mounted horizontally in a one-over-one arrangement with the sap entering the lowest lamp tube and exiting at the highest tube to assure that the UV units are always filled with sap.

The required high pressure and volume are achieved by a positive displacement screw-type pump, with variable speed belt drive to provide flexibility of flow output. The pump delivers from 120 to 480 gallons of sap per hour by changing the variable speed drive, and produces pressures of 300 to 750 p.s.i.g. by adjusting the pump bypass valve. Because at most rural areas where the EUROC plant is to be tested the available electric is limited and is usually supplied as single phase, the pump driving motor is single phase and is limited to 7 1/2 horsepower at 230 volts. To reduce the inductive load at field installations, a capacitor start, capacitor run motor is used to drive the pump. With a unit output of 350 gallons per hour at 600 p.s.i.g., the motor running current is 30 amperes.

The pump bypass valve is a diaphragm-type variable back-pressure regulator which permits manual adjustment of the pump output pressure. This feature limits the required power consumption to that which is necessary to have the plant function properly at the selected conditions.

Pump pressure is indicated on a 6-inch gage, calibrated in 2-pound units. This gage is physically connected to the main feed line immediately upstream from the high-pressure flowrator.

Measurement of sap flow is achieved by passing the sap through an armored flowrator of the variable area type. The sap feed flowrator has a flow range 0 to 8 g.p.m., and consists of two basic elements: (1) A precision metal tapered tube, and (2) a weighed metering element (float). The fluid flow through the meter positions the float according to the flow rate. The float has a stem extending into the extension well which is a nonmagnetic tube above the flowrator housing. Mounted on the float extension is a permanent magnetic armature. The movement of the float and armature is followed by a

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[3] Kissinger, J. C., and Willits, C. O. The control of microorganisms in flowing maple sap by ultraviolet irradiation. Developments in Industrial Microbiology, 7: 318-325. 1966.

magnetic sensing device. This sensing device magnetically couples the motion of the floating disc to the flow indicator gage beam and pointer assembly. The flow indicator assembly is equipped with an electronic transmitter that modulates an electronic signal originating from the remote electronic indicating and control system in proportion to the flow.

The electronic flow indicating and control system consists of four major elements. This system controls the rate of feed through the unit (fig. 6). It also provides the rate of feed, the concentrate flow in gallons per minute, and the total gallons of feed and concentrate flowing.

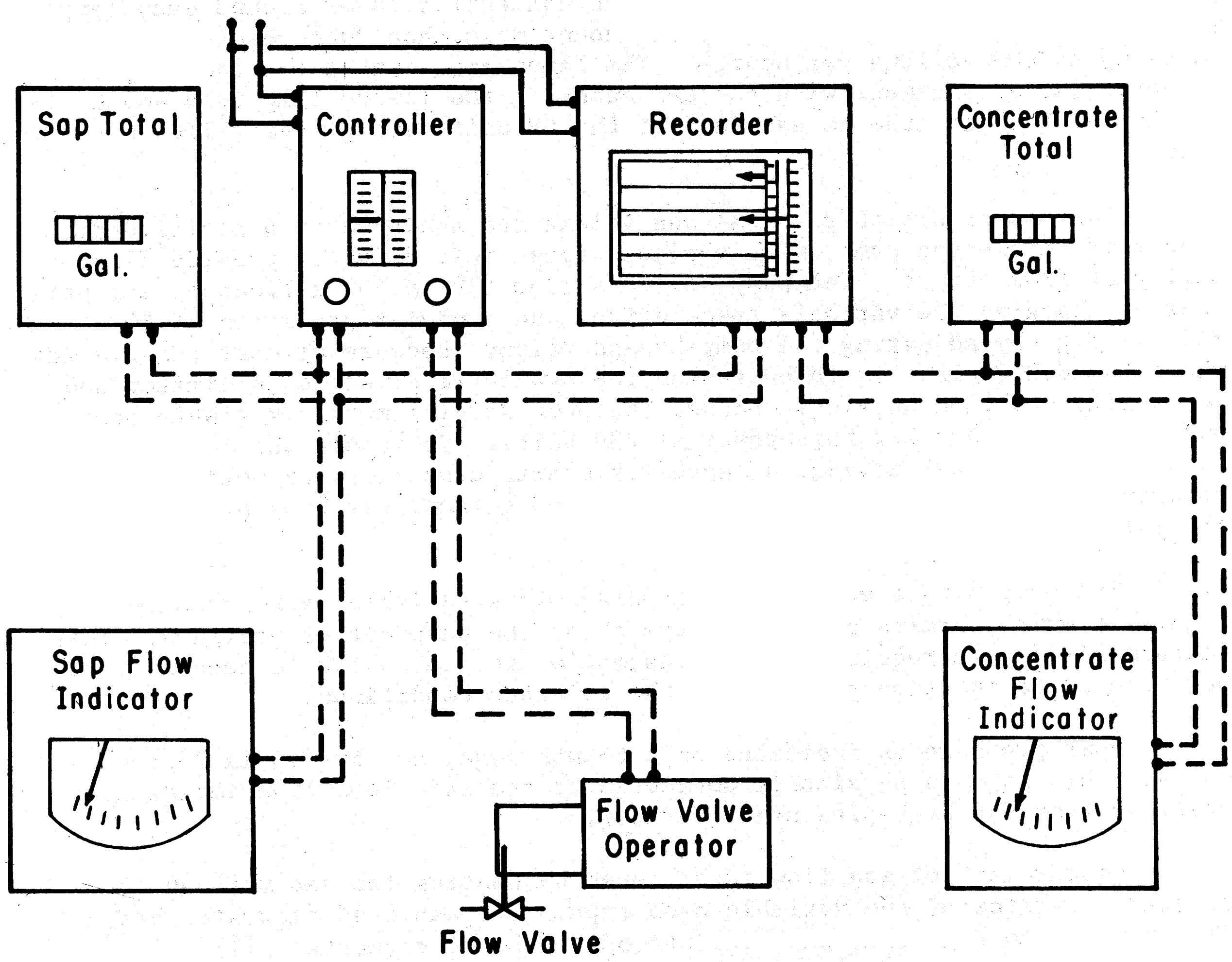

Figure 6.--EUROC flow indicating and control system.

An electronic amplifier in the automatic controller provides control current signal for the system. This control signal is modulated by the flow indicator transmitters and is electronically interpreted by the components of the flow indicating and controlling system to provide the information required. The two volume totalizing units in the system are identical. They provide a digital indication of the volume of sap in tenths of a gallon of sap flowing into the system and the volume of concentrated sap flowing from the unit.

The totalizer is an electronic integrator that integrates the flow signal produced by the transmitter in the flow metering device with respect to time. It is a solid state device that performs the algebraic function of $N = K\int f(T_{in})dt$, where N = tenths of gallons, T_{in} = flow rate signal, K = constant.

A continuous record of the performance of the unit is obtained through the use of a two pen electronic strip recorder. This unit plots the rate of sap flowing into the modules and the concentrate leaving the modules. The recorder accepts the input signal from the flow indicator transmitters and the flow values are continuously indicated on two vertical scales and recorded on a rectilinear strip chart by the two pens. The recorder is a self-balancing potentiometric instrument with a built-in direct current reference supply, transistorized servo amplifier, and balancing motor.

The flow controller permits adjusting the system to any given flow rate and has two modes of operation--automatic and manual. When set in the automatic mode, the unit will automatically adjust the flow control valve to maintain the desired flow; when set in the manual mode, the operator can directly adjust the control valve. The controller accepts the input signal from the sap flow transmitter, compares it with the internal set point signal, and sends a signal to the flow control valve actuator.

The electric actuator of the flow control valve opens and closes the valve to maintain the flow rate in accordance with the indicated requirements. The electric actuator consists of a balancing amplifier, reversible motor, gearbox, and feedback. The gearbox converts the rotary motion of the motor to linear output necessary to operate the valve. The balancing amplifier and feedback operate to keep the input signal from the controller and the valve stem position signal in balance. When the signals are balanced, the error signal is zero and the motor is de-energized and locked in position. Any change in the input signal upsets the balance causing the balancing amplifiers to energize the proper silicon controlled rectifier output circuit to operate the motor to bring the system back into balance. The control valve is a 1-inch globe-type valve with the orifice sized for a 5 pounds per square inch drop through the valve at design conditions.

For stabilization and isolation of the electronic system, an isolation transformer-regulator is used as the power source for the system. This transformer regulates the voltage to maintain 117 volts.

The pressure vessels are 10 feet long, 4 inches in diameter of heavy wall (schedule 80) steel pipe with an internal sanitary epoxy coating. Each pressure vessel contains nine 1-foot long reverse osmosis modules[4/], in series, which provides approximately 100 square feet of membrane surface per pressure vessel. The pressure vessels are sealed at each end with polyvinyl chloride caps bored to receive the module ends and external pipe connections. The caps are held in place by high-pressure Victaulic couplings. This permits easy disassembly for maintenance and inspection.

4/ Willits, C. O., Underwood, J. C., and Merten, U. Concentration by reverse osmosis of maple sap. Food Technology, 21: 24-26. 1967.

The pressure vessels are fed from a valved manifold arrangement which permits the use of a variety of pressure vessel arrangements. The plant is designed to operate with all eight pressure vessels in parallel, in series, or in any combination of series and parallel flow by a simple rearrangement of the piping. The pressurized sap enters the pressure vessel at the right (fig. 1), and passes through the spiral-wound membrane modules. The water that permeates the membrane flows concentrically to the center of the modules to a perforated tube, which conducts it through the center of the pressure vessel. The permeate leaves the pressure vessel at the left end. The remainder of the sap passes successively through each of the modules and the concentrate exits the pressure vessel at the left end. The permeate and concentrate from each pressure vessel may be sampled before reaching their respective manifolds, thus allowing evaluation of the performance of the membranes installed in each pressure vessel.

The concentrate collects in a common manifold, feeds through the back pressure regulating valve, and then exits the EUROC plant. The pressure in the modules is manually set by the operator and is maintained by the back pressure regulator mounted downstream from the concentrate collection manifold. This regulator is the same type used to control the pump output pressure. The permeate flows from the center of the pressure vessels through a flowmeter, collects in a manifold, passes through conductivity meter, and exits the EUROC unit. The valved manifold arrangement, in addition to providing experimental flexibility, permits one or more pressure vessels to be removed for maintenance without requiring shutdown of the entire plant.

A flowrator and flow indicating assembly of the same type as the sap flowrator and flow indicating assembly is installed to indicate the flow rate of the concentrate flowing from the pressure vessels. This flow indicator assembly also sends a modulated signal to the electronic indicating system as discussed above. The volume of concentrate in gallons leaving the system is indicated by the concentrate totalizer and the flow rate is recorded by the second pen of the electronic recorder.

Four flowmeters are installed in the permeate flow stream ahead of the collection manifold to permit simultaneous visual monitoring of the permeate flow from each pressure vessel. Each flowmeter is installed in the output lines of two pressure vessels and, by arranging a pair of three-way valves, the operator can observe the flow rate of permeate from any one of the eight pressure vessels or the output of each pair of pressure vessels can be put through the flowmeter. By paralleling two pressure vessels at each flowmeter, the operator can easily monitor the permeate (water) output of all pressure vessels and detect a module failure by comparing the relationship of the flow indicated by each of the flowmeters.

These flowmeters have an equal area 3/4 inch metering tube with a precision float. The meter flow range is 0 to 2 gallons per minute. The metering tube and float can be removed for cleaning and service while the meter body remains in the line.

To monitor the quality of the permeate continuously, a conductivity indicator is placed downstream from the collection manifold. This meter can be set to indicate when the impurity of the permeate exceeds the desired limits, thus signaling a breakdown in one or more of the reverse osmosis membranes.

DISCUSSION

The only power required by the EUROC plant is 6.4 kw. of electric power to process 350 gallons of sap per hour at 600 p.s.i.g. The plant reaches a stable operating condition one-half hour after start up. At design flow conditions the plant should remove about 75 percent of the water from the sap in one passage through the unit.

This plant, constructed at the Eastern Utilization Research and Development Division for experimental purposes, cost approximately $28,000, including design, parts, and fabrication. This cost would be appreciably lower if the reverse osmosis membranes had been a production item at the time of construction. Also, commercial application of this unit needs neither the expense of the electronic control system nor the use of a portable frame. A simple production apparatus for the reverse osmosis concentration of maple sap the size of the EUROC could be assembled by a producer for approximately $3,000 to $4,000, plus the cost of the reverse osmosis membranes and pressure vessels.

In principle, the EUROC machine economically outperforms the present thermal concentration methods on a short-run basis. The feasibility of the use of reverse osmosis for concentration of maple sap is dependent upon the life of the reverse osmosis membranes versus the capital investment they represent.[5/] This consideration is still under study at the Eastern Utilization Research and Development Division (EURDD), ARS, USDA, Wyndmoor, Pa. 19118.

Underwood and Willits[5/] reported on the performance and operational characteristics of this plant based on the 1968 sap flow season.

All parts of this machine were made by well-known manufacturers and are readily available on the open market. Personnel of EURDD sized, assembled, and adjusted these parts. The writers will supply further details on the apparatus as a whole or any part of it upon request.

5/ Underwood, J. C., and Willits, C. O. Operation of a reverse osmosis plant for the partial concentration of maple sap. Food Technology 23: 787-790. 1969.